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AN IMPROVED AUTOMOTIVE BRAKE LINING
USING FIBROUS POTASSIUM TITANATE

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16. Abstract

Simultaneous fade reduction and wear improvement of a commercial automotive brake lining were achieved by adding fibrous potassium titanate. The dependence of friction and wear characteristics on quantitative variations in potassium titanate, asbestos, phenolic binder, and organic and inorganic modifiers are presented.

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AN IMPROVED AUTOMOTIVE BRAKE LINING

USING FIBROUS POTASSIUM TITANATE

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SUMMARY

Simultaneous fade reduction and wear improvement of automotive brake linings were achieved by adding fibrous potassium titanate.

A study of the effects of adding potassium titanate fiber to friction composites which were otherwise comprised of phenolic binder, asbestos fiber and organic and inorganic modifiers was conducted. The relative quantities of these major ingredients were varied, and the effects of replacing part of the asbestos with an equal volume of potassium titanate fiber were:

1. A significant increase in high-temperature friction, even at high binder contents, with some evidence that friction is an increasing function of the potassium-titanate-fiber-to-asbestos ratio.

2. A comparatively constant friction as a function of temperature at titanate-to-asbestos ratios of 1.5.

3. No pronounced change on low-temperature friction.

4. Decreased high-temperature (above 450°F (222°C)) wear rate at binder contents near 24 volume percent for titanate-to-asbestos ratios of 1.0 and 1.5, and increased high-temperature wear rate at binder contents near or below 22 volume percent.

5. No significant change in low-temperature (below 450°F (222°C)) wear, except for some wear impairment at the binder content of 18 percent.

The addition of fibrous potassium titanate to a commercial brake lining resulted in a significant fade reduction, a wear improvement of 46 percent averaged over the temperature range of 400° to 650°F (204° to 343°C), and no wear change at lower temperatures.

INTRODUCTION

The search for friction materials with better friction stability has been a continuing one in the automotive industry; however, new federal regulations which will limit vehicle stopping distances have added impetus to efforts to develop fade-resistant brake materials (ref. 1). Being sought are

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new materials with friction characteristics that are less sensitive to temperature and that have better high temperature wear resistance.

In this study, the effects on friction and wear of adding potassium titanate fiber to brake materials containing asbestos, phenolic binders, and organic and inorganic modifiers, was explored. Our objective was the achievement of simultaneous improvements in friction and wear characteristics of a commercial brake lining by adding fibrous potassium titanate.

MATERIALS AND TESTING PROCEDURES

Materials

The potassium titanate used in this work was an insoluble fibrous form distributed under the trade name "Fybex" by E. I. DuPont de Nemours and Company. Some of its properties are listed in table 1, and additional properties are given by Linsen and Regester (ref. 2). This potassium titanate was selected because of its high thermal stability and because of its low hardness compared to those of asbestos and asbestos degradation products.

TABLE 1.– PROPERTIES OF FIBROUS POTASSIUM TITANATE

Formula	$(K_2O)_x (TiO_2)_z, Z/X \sim 8$
Average fiber length, μm	8–10
Average fiber diameter, μm	0.10–0.15
Melting point, °F (°C)	2300–2390 (1260–1310)
Moh hardness	3
Density, g/cm³	~ 3.3
BET N_2 surface area, m^2/g	7–10

Potassium titanate fiber was added to two types of composite matrices, referred to below as composite types A and B. Both types comprised asbestos fiber, phenolic-base binder, and organic and inorganic modifiers. Types A and B differed in that an ingredient for one type was not chemically identical to the corresponding ingredient of the other; for example, the phenolic binders of the two types are not identical. The properties of composites with potassium titanate fiber added were compared to the properties of composites of the same type that did not contain potassium titanate. The latter are hereafter referred to as standard composites A and B. The formulations of the standard composites are given in table 2. For reasons described below, comparisons are made to three standard composites of Type A. The single standard composite B is a commercial lining suitable for secondary lining applications in automobiles and light trucks; it meets 1973 federal specifications for certain government vehicles.

Ranges over which the ingredient quantities were varied for the experimental composites, that is, composites containing potassium titanate fiber, are given in table 3. In table 3, binder content is given as the percentage of the total volume, whereas composition for the remaining ingredients is expressed as the ratio of the volumes of two ingredients; composition is hereafter expressed in this manner.

TABLE 2.– STANDARD COMPOSITE FORMULATIONS

| Ingredient | Ingredient content, % volume | | | |
	Type A (standard composites)			Type B (standard composite)
Phenolic binder	18	21	24	15
Chrysotile asbestos fiber	36.2	34.8	33.6	37.5
Organic modifiers (principally Cashew friction particle)	35.3	34.0	32.6	36.5
Inorganic modifiers	10.5	10.2	9.8	11

TABLE 3.– INGREDIENTS RANGES FOR EXPERIMENTAL COMPOSITES

	Type A	Type B
Binder content, % volume	18–24	15–24
Ratio of potassium titanate fiber to asbestos	0.25–1.5	0.33–1.0[a]
Ratio of fiber (titanate plus asbestos) to modifier	0.79	0.73–0.88
Ratio of inorganic to organic modifiers	0.30	0.30

[a]Type B composites with titanate-to-asbestos ratios larger than one were fabricated but not tested due to ingredient nonuniformities.

It can be seen from table 3 that there was no variation in the ratio of fiber to modifier for composites of Type A, nor in the ratio of inorganic to organic modifiers for either Type A or B composites. The values of these constant ratios are the same as that of the corresponding standard composite.

Standard and experimental composites of types A and B were fabricated by a conventional compression molding technique. The composite ingredients were dry-blended, molded at 350°F (177°C) and 6000 psi ($4 \times 10^7 N/m^2$) for 15 min., and cured at 500°F (260°C) for 8 hr. A P-K cantilever twin shell laboratory blender was used for mixing, and, for samples containing potassium titanate, an intensifier bar was used to facilitate homogeneous blending.

Testing Procedures

The friction and wear measurements were conducted with a drag dynamometer (Chase machine) at temperatures from 250° to 650°F (122° to 343°C). A series of 40 applications of the composite sample against a rotating cast-iron drum was conducted at each temperature, with the sample-drum sliding speed maintained at 25 ft/sec (7.6 m/sec). The output torque was held constant at 350 in.-lb (4.0 kgf-m), and the normal load necessary to maintain the torque, averaged over 40 applications, provided the measure of friction coefficient. Sample wear at each temperature was determined by measuring the cumulative dimensional and weight loss resulting from the 40 applications. The composite sample size was 1 x 1 x 3/8-in. thick (2.5 x 2.5 x 1 cm). The drum had

an 11-in.(28 cm) i.d., and its composition corresponded to the specifications given in SAE Standard J661a (ref. 3). The drum temperature was measured through a slip-ring assembly with a chromel-alumel thermocouple located at the center of the wear track, 0.050 in.(0.13 cm) below the friction surface. An auxiliary heater-blower system was available for use in maintaining the desired temperature.

RESULTS AND DISCUSSION

The results are presented in four sections. In the first, the maximum amounts of potassium titanate fiber that could be added at given resin levels are presented for both type A and B composites. These upper limits of concentration were not systematically explored, but several compositions were encountered in which a limit was apparently approached or exceeded.

The second and third sections present the friction and wear results for Type A composites. In both sections, comparisons are given between standard composites and composites that contain potassium titanate, but the type and purpose of the comparisons differ in the two sections. In the second, the effect of replacing part of the asbestos with potassium titanate is isolated by comparing the three standard composites (table 2) to experimental composites that are identical except that a fraction of the asbestos has been replaced by the titanate. In the third, the friction and wear of composites containing potassium titanate fiber are compared to those of the "primary standard"; the primary standard is chosen as the standard composite of Type A that has the lowest wear rate of those standards whose high-temperature ($\geq 550°F$ ($288°$ C)) friction coefficient remains above 0.2. The comparisons in this section illustrate the maximum magnitudes (approximate) of simultaneous friction and wear improvement that can be achieved by incorporating the titanate fiber into Type A composites. They also indicate the compositions required to achieve the improvements, and thus serve as an introductory guide to further development work.

In the fourth section, the best overall friction and wear improvements achieved by the addition of potassium titanate fiber to the commercial lining formula, Type B, are presented.

Upper Limits of Potassium Titanate Fiber Addition

The quantity of potassium titanate that could be effectively introduced into composite matrices of this type was found to be limited in that it became difficult to fabricate uniform and cohesive composites, or the composite formed had inadequate strength for braking application, or both. Specific cases where a limit was exceeded or apparently approached are cited below.

In the case of Type A composites, there was evidence of hairline surface cracking after dynamometer testing for samples with a titanate-to-asbestos ratio of 1.5 at 21 percent binder. Note that a titanate-to-asbestos ratio of 1.5 implies that three-fifths of the original asbestos has been replaced by titanate. Evidently the binder requirements for the composite resulting from addition of such a large quantity of titanate have been exceeded. Cracking was not evident for this or lower fiber ratios at the higher binder contents of 22.5 or 24 percent.

For composite B samples, normal processing procedure resulted in noncohesive, nonuniform samples for composites whose fiber content was wholly or predominantly potassium titanate (60 to

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100 percent asbestos replacement) at a binder content level of 15 percent. Efforts to improve binder dispersion by appropriate solvents provided no observable improvement at this binder content. When the titanate to asbestos ratio was reduced to 1 or less, uniform samples could be fabricated with normal processing at binder contents of 15 percent or greater. At a titanate-to-asbestos ratio of 1 and binder content of 15 percent, composite shear strength was 710 psi $(4.9 \times 10^6 \text{N/m}^2)$, a 50 percent reduction from that of the Type B standard composite; however, this experimental composite underwent successful dynamometer testing. At a titanate-to-asbestos ratio of 1, the higher binder content of 21 percent resulted in a shear strength of 960 psi (28 percent below the standard), whereas the strength for 24 percent binder was 1350 psi (the same as the standard).

Friction and Wear Effects — Type A Composites

In this section, the friction and wear for composites containing asbestos as the only fiber are compared to composites that are identical in every respect except that part of the asbestos has been replaced by an equal volume of potassium titanate fiber. The comparison is at binder contents of 18, 21, and 24 percent. For the experimental samples, the titanate-to-asbestos ratios ranged from 0.25 to 1.5, corresponding to replacemnt of one-fifth to three-fifths of the asbestos by titanate, respectively.

Friction improvement. — Comparisons in friction level, presented as curves of coefficient of friction as a function of temperature, are given in figures 1-3. The partial replacement of asbestos with titanate has provided higher friction at the high temperatures of 550° and 650°F (288° and 343°C) in all cases; the increase is substantial in most cases. It appears from figures 1 and 2 that the high-temperature friction is an increasing function of the titanate-to-asbestos ratio, for 18 and 21 percent binder. The apparent exception at 24 percent binder (fig. 3) may be a consequence of statistical variation. The effects of the asbestos replacement on low temperature friction, below 450°F (232°C), tend to be less pronounced, the friction falling slightly and somewhat irregularly above and below that for the corresponding standard. A possible trend can be seen at 350°F
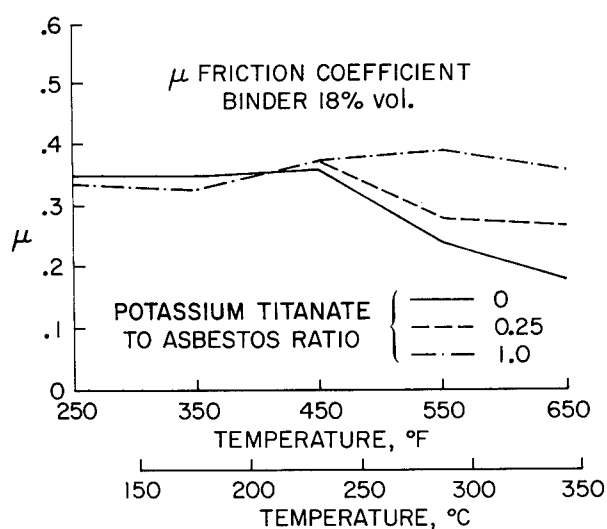

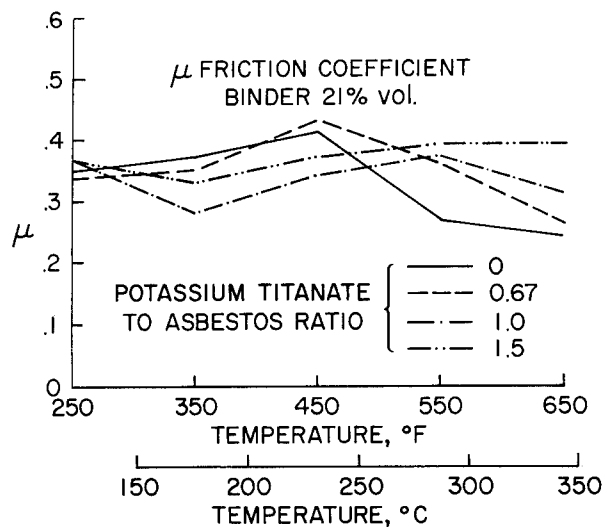Figure 1.— Friction vs temperature for type A composites at 18% volume binder.

Figure 2.— Friction vs temperature for type A composites at 21% volume binder.
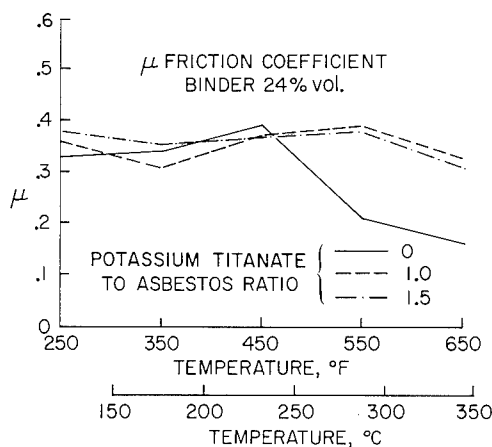
5

Figure 3.— Friction vs temperature for type A composites at 24% volume binder.

(177°C) on figures 2 and 3, the friction first decreasing and then increasing with increasing titanate-to-asbestos ratio. Considering the friction curves over the entire temperature range, the friction is comparatively constant with temperature for titanate-to-asbestos ratios of 1.5. For example, the friction range is 0.33 to 0.39 for a binder content of 21 percent and 0.32 to 0.38 for a binder content of 24 percent.

With thermal stability as an important controlling factor, we would expect increased high-temperature friction as the titanate-to-asbestos ratio is increased in an otherwise fixed composition. Alternatively, at fixed titanate-asbestos ratios, increasing the binder con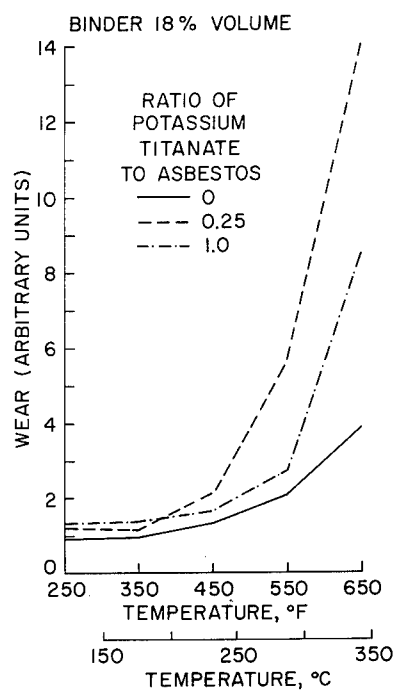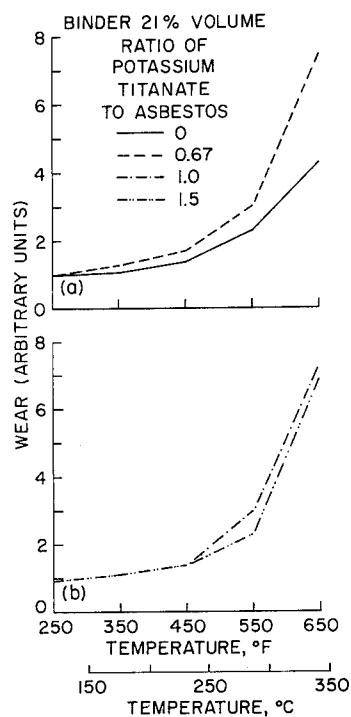tent can result in a decrease of high-temperature friction. Keeping these considerations in mind, and knowing that the potassium titanate fiber may require an unusually large binder content, it was necessary to clarify whether the probable friction-increasing effect of the titanate would be suppressed by the detrimental effect on friction to be expected from the increased binder content. It was also desirable to know how broad a composition range, over which significant friction enhancement occurs, is available. From figures 1-3, it is established that significant high-temperature-friction stability can be achieved by the addition of potassium titanate fiber over a broad range of composition.

Wear improvement. — The effect on wear of the partial replacement of asbestos by potassium titanate fiber, at various resin contents of the composite, is shown in figures 4-6 as a function of temperature. The four curves in figure 5 are shown on two plots for clarity of presentation, only. It is clear, first of all, that, at temperatures below 450°F (232°C), wear is comparatively small and wear differences among the standard and experimental composites are small. This relatively low wear, showing little temperature dependence, is typical of that found in the abrasion/adhesion wear region (refs. 4, 5) and does not allow us to positively differentiate between the various friction materials. At temperatures above 450°F (232°C), however, increased wear and wear differences become apparent as the binder and other organic components pass into the thermal decomposition region (ref. 6). Not only is it easy now to differentiate between the various composites, but trends can be discerned as functions of the titanate-to-asbestos ratio and of the resin content. The former will be discussed in greater detail below, while the latter has already been alluded to by reference to the high binder content required by the titanate fiber.

Whereas the standard composites at all three resin levels have quantitatively similar wear versus temperature curves, the introduction of potassium titanate fiber causes dramatic changes in their behavior. For the case of 18 and 21 percent resin, a significant increase in wear is observed, the largest change coming about with the lowest resin content. When the resin content is raised to 24 percent, a reversal takes place and an improvement in the wear of the material is brought about by the replacement of some of the asbestos by the potassium titanate fiber.

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BINDER 18% VOLUME

RATIO OF
POTASSIUM
TITANATE
TO ASBESTOS
——— 0
– – – 0.25
–·–·– 1.0

WEAR (ARBITRARY UNITS)

TEMPERATURE, °F

TEMPERATURE, °C

Figure 4.— Wear vs temperature for
type A composites with 18% vol-
ume binder.

BINDER 21% VOLUME

RATIO OF
POTASSIUM
TITANATE
TO ASBESTOS
——— 0
– – – 0.67
–·–·– 1.0
–··–··– 1.5

WEAR (ARBITRARY UNITS)

(a)

(b)

TEMPERATURE, °F

TEMPERATURE, °C

Figure 5.— Wear vs temperature
for type A composites with
21% volume binder.

BINDER 24 % VOLUME

RATIO OF
POTASSIUM
TITANATE
TO ASBESTOS
——— 0
– – – 1.0
–·–·– 1.5

WEAR (ARBITRARY UNITS)

TEMPERATURE, °F

TEMPERATURE, °C
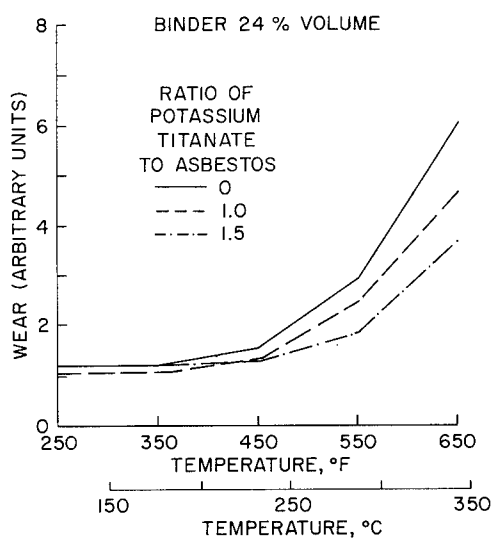
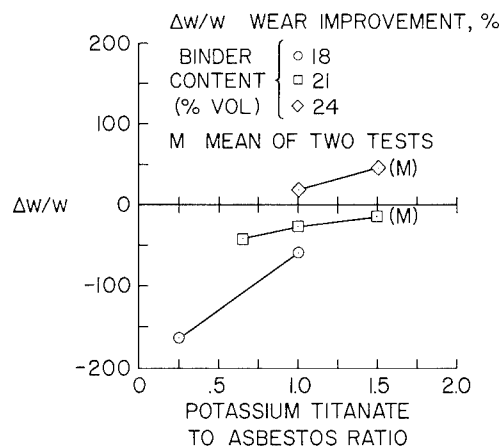Figure 6.— Wear vs temperature for type A composites with 24% volume binder.

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Figure 7.– The effect on wear at high temperature (≥450°F or 232°C) of the partial replacement of asbestos with potassium titanate fiber.

The effect of variation in titanate-to-asbestos ratio on high-temperature wear can be seen more clearly in figure 7. The data in figure 7 have been averaged from measurements at 450°, 550°, and 650° F (222°, 288°, and 343° C). Wear improvements on this figure and subsequent analogous figures represents the comparative life of the composites with and without potassium titanate fiber. For example, a wear improvement of +50 percent indicates that the life of the experimental composite would be 50 percent longer than that of the standard composite (i.e., $\Delta W/W = (w$ standard $- W$ experimental$)/W$ experimental). A negative value of 50 percent indicates that the lifetime of the standard would be 50 percent larger than that of the experimental (i.e., $\Delta W/W = (W$ standard $- W$ experimental$)/W$ standard).

It can be seen from the positive slopes and relative position of the three curves in figure 7 that high-temperature-wear improvement is an increasing function of titanate-to-asbestos ratio as well as binder content. The upper limit of the titanate-to-asbestos ratio is evidently about 1.5 for binder contents of 21 percent, as discussed above. Therefore, the trends of figure 7 indicate that the replacement of asbestos with titanate has a deleterious effect on high-temperature wear at binder contents near or below 21 percent, because the improvement is negative. For 24 percent binder, however, the replacement has a beneficial effect, to values as high as 55% improvement for the titanate-to-asbestos ratio of 1.0 and 1.5.

Within certain limitations, the wear of composite systems without titanate, such as those of type A, tends to decrease with increasing binder content, with the accompanying tendency toward increased fade. Since the introduction of potassium titanate fiber tends to reduce fade significantly, its introduction permits higher binder content without fade. In that manner, potassium titanate fiber may be viewed as a wear-reducing agent. If that were to describe the sole mechanism of wear improvement for composites containing titanate, no wear improvements above zero on figure 7 would be obtained. The positive wear improvements obtained with 24 percent binder suggest that the potassium-titanate-fiber replacement of asbestos has resulted in wear reduction above that due to the greater resin content. We may conclude that a difference between one or more of the properties of asbestos and potassium titanate fiber, including their manner of interacting with other ingredients, has contributed to wear improvement.

For low-temperature wear, the data differences are comparatively small (in most cases, less than the estimated uncertainty), and trends cannot be established. The data are presented on figure 8, primarily to indicate their general magnitude. There is little, if any, wear improvement for any case, and the replacement may impair wear at the lower binder content of 18 percent. The data of figure 8 are averaged over measurements at temperatures of 250°, 350°, and 450° F (122°, 177°, and 222° C); differences between data averaged over the lower of these two temperatures are negligible.
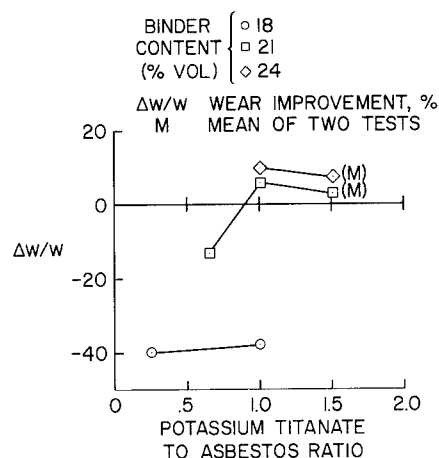
8

BINDER
CONTENT { o 18
(% VOL)   □ 21
          ◇ 24

Δw/w   WEAR IMPROVEMENT, %
M   MEAN OF TWO TESTS

POTASSIUM TITANATE
TO ASBESTOS RATIO

Figure 8.— The effect on wear at low temperature (≤ 450°F) or 232°C) of the partial replacement of asbestos with potassium titanate fiber.

Friction and Wear Compared to Primary Standard A

Comparisons given in the preceding section do not reveal the maximum simultaneous friction and wear improvements that the addition of a new ingredient can produce, compared to any of a large possible number of "best compromise" compositions for that set of ingredients. Since a survey of friction-and-wear properties over the complete composition range of type A composites was not possible, simultaneous improvement magnitudes cannot be established. However, in order to obtain an indication of the possible improvements, comparisons are made here to the previously described "primary standard," which had the lowest wear rate among the standards of type A whose friction at high temperature remained above 0.2. It is the type A standard composite with 21 percent binder (composition given in table 2). It was clearly the "best" standard in that its high-temperature friction was not exceeded by any other standard, and its wear was only negligibly higher than one other standard and that standard exhibited extreme fade.

Friction and wear improvements compared to the primary standard are given in figure 9. The friction values are based on measurements at 550° and 650° F (288° and 343° C) and the wear from measurements at 450°, 550°, and 650° F (222°, 288°, and 343° C). It can be seen from the wear improvement curves in figure 9 that, relative to the primary standard, high-temperature-wear improvements would require binder contents
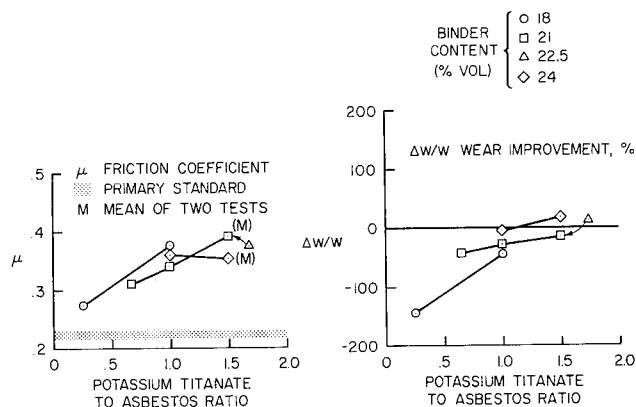

BINDER
CONTENT { o 18
(% VOL)   □ 21
          △ 22.5
          ◇ 24

μ   FRICTION COEFFICIENT
    PRIMARY STANDARD
M   MEAN OF TWO TESTS

Δw/w   WEAR IMPROVEMENT, %

POTASSIUM TITANATE
TO ASBESTOS RATIO

Figure 9.— Friction at high temperature (≥550°F or 288°C) and wear improvement at high temperature (≥450°F or 232°C) relative to primary standard A.

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near or above 24 percent and potassium-titanate-to-asbestos ratios near or above unity. Fade would not be significant at those compositions, but the potential wear improvements are small, of the order of 20 percent.

The indications of maximum improvement in this comparison are subject to an interpretation problem, which is described below. First, composition changes that reduce fade tend to increase wear, as was established for composites of this general type by M. Jacko et al. (ref. 7). It was shown that in varying compositions from those that exhibit extreme fade to those that exhibit no fade, wear rate increased by a factor of over 2.5. On the basis of its composition and comparative fade and wear characteristics, the primary standard used in the above comparisons would tend to be classed as a high-fade, low-wear composite. The ability of potassium titanate fiber to eliminate the fade in such a composition without impairing the wear has the following consequences: If, in a particular application, relatively high fade is acceptable, but wear improvements are desired, potassium titanate fiber can be of limited benefit; it could be used to reduce the fade, a factor of little concern, and to provide only minor wear improvements, as shown on figure 9. However, if a particular application demands low fade, and comparatively high wear has been accepted but is not desired, potassium titanate fiber can provide significant benefit. The titanate fiber can be added to a high-fade, low-wear composition to provide a composite with essentially no fade, and a wear substantially lower than that of the previously accepted low-fade composite.

Extrapolation of the wear trends shown in figure 9 to higher values of binder content and higher titanate-to-asbestos ratios, suggests that higher positive improvements in high-temperature wear than those are shown may be attained. This has not been explored, but it should be noted that an increasing difficulty of fabricating uniform samples was experienced with increasing titanate-to-asbestos ratios. This was found even as binder content was increased to accommodate the titanate, and the higher binder-titanate levels shown may be approaching a practical limit.

Wear improvement at low temperatures is shown in figure 10; the values given are averaged over measurements at 250°, 350°, and 450° F (122°, 177°, and 222 ° C). Values and data trends for values based on 250° F, or on the average over 250° and 350° F, closely approximate those given. As in the preceding section, the small differences in wear improvement at low temperature will not permit trends to be established, and wear is approximately equal to that of the standard except for wear impairment at low binder content.
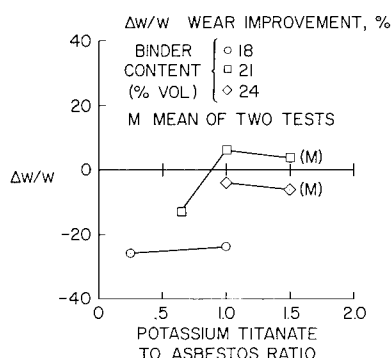
Improvements in Type B Composite

The friction and wear as functions of temperature for the commercial brake lining, standard composite B, are given in figure 11. Data scatter from a large number of tests is indicated in figure 11; note particularly the large scatter in wear measurements at temperatures above 550° F (288° C).

Figure 10.— Wear improvement at low temperature ($\leq$450°F or 232°C) relative to primary standard A.

The friction and wear of the optimum experimental composite (exhibiting the best overall characteristics of any composite comprising potassium titanate fiber in composite

matrix B) are compared to those for standard composite B in figure 12. The data points pertaining to the experimental composite are based on the mean from two tests. The combined uncertainty from the individual uncertainties of the data for the standard and experimental composites, are indicated.

The optimum experimental composite contains 21 percent binder, a 40 percent increase above the 15 percent binder of the standard. It has a fiber-to-modifier ratio of 0.81, the same as for the standard, and a potassium-titanate-fiber-to-asbestos ratio of 1.0.

Significant improvements are noted in fade reduction and high-temperature wear. Averaged over 400° to 650° F (204° to 343° C), the wear improvement is 46 percent, whereas, for temperatures below 400° F (204° C), the wear of the optimum composite is the same as that of the standard. The low-temperature friction of the optimum is substantially lower than that of the standard. The improvements achieved are similar to the maximum improvements indicated in the preceding section, although the two composite systems are not the same.
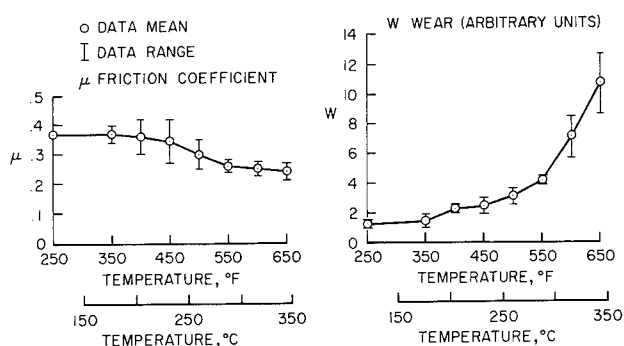

Figure 11.— Friction and wear characteristics of the standard commercial brake lining.
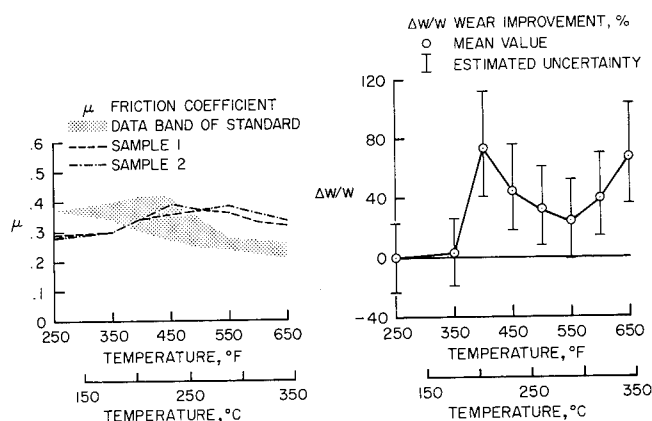
Figure 12.— Friction and wear improvement of the optimized experimental composite of type B.

In the process of establishing the optimum composition, measurements were conducted for a number of composites whose compositions were near the optimum. Variations in composition of fiber-to-modifier ratio, potassium-titanate-to-asbestos ratio, and binder content were tested at values somewhat above and below that of the optimum. The specific compositions (including the optimum composition) are listed in table 4. Tests at titanate-to-asbestos ratios greater than 1, that is, greater than for the optimum, were not made because of difficulty with composite processing. Wear was greater than for the optimum at high temperatures for all compositions tested and was also greater than the optimum at low temperatures for many compositions. The composition that was most competitive with the optimum in high-temperature wear was for the lower fiber-to-modifier ratio of 0.73 (composition number 2 in table 4); the friction coefficient for this composition did not fall below 0.3 at high temperature. The wear was also comparatively low for the composition containing 24 percent binder (composition number 7), although this composition exhibited high fade. Composition number 3, which had the higher fiber-to-modifier ratio (0.88), exhibited the least variation in friction with temperature, with the friction coefficient ranging from 0.32 to 0.36. The high-temperature wear for this composition was a substantial improvement over that of the standard

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TABLE 4.– TYPE B COMPOSITIONS TESTED

Composition number	Ratio of potassium titanate to asbestos	Binder content % vol	Fiber to modifier ratio
1[a]	1.0	21	0.81
2	1.0	21	0.73
3	1.0	21	0.88
4	1.0	18	0.81
5	1.0	20	0.81
6	1.0	22	0.81
7	1.0	24	0.81
8	0.67	21	0.81

[a]Optimum composition

composite, but the low-temperature wear was particularly high. The lower potassium-titanate-to-asbestos ratio of 0.67 (composition number 8) resulted in the highest overall wear of any composition listed in table 4, and the friction coefficient at high temperature was as low as 0.2.

CONCLUSIONS

The effects of replacing part of the asbestos with an equal volume of potassium titanate fiber in type A composites were:

1. A significant increase in high-temperature friction, even at high binder contents, with some evidence that friction is an increasing function of the potassium-titanate-fiber-to-asbestos ratio.

2. A comparatively constant friction as a function of temperature at titanate-to-asbestos ratios of 1.5.

3. No pronounced change on low-temperature friction.

4. Decreased high-temperature (above 450°F (222°C)) wear rate at binder contents near 24 volume percent for titanate-to-asbestos ratios of 1.0 and 1.5, and increased high-temperature wear rate at binder contents near or below 22 volume percent.

5. No significant change in low-temperature (below 450°F (222°C)) wear, except for some wear impairment at the binder content of 18 percent.

Based on comparison to a particular composition found to have the best overall friction and wear properties among four standard compositions of type A, simultaneous friction and wear improvements can be achieved by the addition of potassium titanate fiber as follows: Over the range

of binder content and titanate-to-asbestos ratios examined, maximum improvements in high-temperature wear are limited to about 20 percent, and required binder contents of about 24 percent and titanate-to-asbestos ratios of about 1.5. Although extrapolation of trends to higher binder contents and fiber ratios suggests further possible improvement, there is evidence that fabrication of these composites would be difficult. The composition required for high-temperature-wear improvement also results in significant fade reduction. Effects on low-temperature wear are minor.

Improvements of the commercial brake lining, type B, through the addition of potassium titanate fiber were achieved. Significant fade reduction was achieved, although the friction of the improved composite was lower than that of the commercial lining at low temperature. An average wear improvement of 46 percent was achieved over the intermediate- and high-temperature range, and wear of the improved composite was equivalent to that of the commercial lining at low temperatures.

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        Moffett Field, Calif. 94035, August 27, 1976

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